Lewis, Monica

From: Lewis, Monica
Sent: Monday, July 22, 2013 1:19 PM
To: Lewis, Monica
Subject: FORWARD - FW: DOE FOIA Documents
Attachments: EPA Transfer.pdf

-----Original Message-----
From: Twardzik, Lori (CONTR) [mailto:Lori.Twardzik@Hq.Doe.Gov]
Sent: Monday, July 22, 2013 9:22 AM
To: Lewis, Monica
Subject: DOE FOIA Documents

Dear Ms. Lewis,

I've attached the EPA documents referenced in the memo you received regarding DOE's FOIA request #HQ-2012-01625-F. I apologize for the error and any ensuing confusion.

Please feel free to contact me with any questions or concerns.

Thanks for your patience, and have a great day!

Sincerely,
Lori Twardzik, Esq.
FOIA Analyst
eGlobalTech
Contractor to the Department of Energy
Office of Information Resources
1000 Independence Ave, SW
Washington, DC 20585
(202)586-6859

Department of Energy
Washington, DC 20585
June 12, 2013

Larry F. Gottesman
National FOIA Officer
The Environmental Protection Agency
Mail Code 2822T
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Re: HQ-2012-01625-F

Dear Mr. Gottesman:

The Department of Energy (DOE) received the enclosed request from Ms. Sharla Manley under the Freedom of Information Act (FOIA), 5 U.S.C. 552. Ms. Manley asked for:

1. All records concerning the "Big Wind Projects" component of the Energy Agreement Among the State of Hawaii, Division of Consumer Advocacy of the Department of Commerce and Consumer Affairs, and the Hawaiian Electric Companies dated October 2008 (the Agreement), including:

    a. All correspondence, including emails, between the DOE and the Hawaiian Electric Companies about the "Big Wind Projects";

    b. All correspondence, including emails, between the DOE and Division of Consumer Advocacy about the "Big Wind Projects";

    c. All correspondence, including emails between the DOE and the Department of Business, Economic Development, and Tourism about the "Big Wind Projects";

2. All documents generated by or at the direction of William Parks of the DOE and related to the "Big Wind Projects"

3. All records of meetings leading to the creation of the Agreement.

4. All records relating to drafts of the Agreement.

5. All records of federal funds expended to formulate and complete the Agreement.

6. All records of federal funds expended to implement the "Big Wind Projects."

7. All records of federal assistance provided to implement the "Big Wind Projects" including but not limited to loan guarantees, tax credits, and tax deductions.

On January 16, 2013, the request was assigned to the DOE Office of Electricity Delivery and Energy Reliability (OE) for a search of its files for responsive documents. During that search, OE identified one document that originated with your agency. For this reason, I am referring it to you to review for a release determination and direct response to the requester.

If you have any questions about this correspondence, please contact Ms. Joan Ogbazghi or Ms. Emily Peterson-Cassin of my staff at (202) 586-5955. I appreciate your assistance with this matter.

Sincerely,

Alexander C. Morris
FOIA Officer
Office of Information Resources

Enclosures

NATIVE HAWAIIAN LEGAL CORPORATION
Serving Hawai'i since 1974

1164 Bishop Street, Suite 1205 • Honolulu, Hawai'i 96813 • Phone (808) 521-2302 • Fax (808) 537-4268

June 29, 2012

VIA U.S. MAIL

JUL 12 2012 02

FOIA Officer
U.S. Department of Energy, FOIA Requester Service Center
1000 Independence Ave., SW
Washington, D.C. 20585

RE: FREEDOM OF INFORMATION REQUEST

Dear Sir or Madam:

The Native Hawaiian Legal Corporation, on behalf of Kaulana Kahoohalahala, Halona Kaopuiki, and Matthew Mano, and pursuant to the Freedom of Information Act, and the Department of Energy Regulations, 10 C.F.R. Part 1004, requests the following records that are related to the ENERGY AGREEMENT AMONG THE STATE OF HAWAII, DIVISION OF CONSUMER ADVOCACY OF THE DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS, AND THE HAWAIIAN ELECTRIC COMPANIES.

1. All records concerning the "Big Wind Projects" component of the ENERGY AGREEMENT AMONG THE STATE OF HAWAII, DIVISION OF CONSUMER ADVOCACY OF THE DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS, AND THE HAWAIIAN ELECTRIC COMPANIES, including:

   a. all correspondence, including emails, between the U.S. Department of Energy and the Hawaiian Electric Companies about "Big Wind Projects" component of the "ENERGY AGREEMENT AMONG THE STATE OF HAWAII, DIVISION OF CONSUMER ADVOCACY OF THE DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS, AND THE HAWAIIAN ELECTRIC COMPANIES" (dated October, 2008);

HQ-2012-01625-F

Services made possible with major funding from the Office of Hawaiian Affairs.

b. all correspondence, including emails, between the U.S. Department of Energy and Division of Consumer Advocacy of the Department of Commerce and Consumer Affairs about: the "Big Wind Projects" component of the "ENERGY AGREEMENT AMONG THE STATE OF HAWAII, DIVISION OF CONSUMER ADVOCACY OF THE DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS, AND THE HAWAIIAN ELECTRIC COMPANIES" (dated October, 2008);

c. all correspondence, including emails, between the U.S. Department of Energy and the Department of Business, Economic Development and Tourism about: the "Big Wind Projects" component of the ENERGY AGREEMENT AMONG THE STATE OF HAWAII, DIVISION OF CONSUMER ADVOCACY OF THE DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS, AND THE HAWAIIAN ELECTRIC COMPANIES (dated October, 2008).

2. All documents generated by or at the direction of William Parks of the U.S. Department of Energy, and related to the "Big Wind Projects" component of the ENERGY AGREEMENT AMONG THE STATE OF HAWAII, DIVISION OF CONSUMER ADVOCACY OF THE DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS, AND THE HAWAIIAN ELECTRIC COMPANIES (dated October, 2008).

3. All records of meetings leading to the creation of the ENERGY AGREEMENT AMONG THE STATE OF HAWAII, DIVISION OF CONSUMER ADVOCACY OF THE DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS, AND THE HAWAIIAN ELECTRIC COMPANIES (dated October, 2008).

4. All records relating to drafts of the ENERGY AGREEMENT AMONG THE STATE OF HAWAII, DIVISION OF CONSUMER ADVOCACY OF THE DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS, AND THE HAWAIIAN ELECTRIC COMPANIES (dated October, 2008).

5. All records of Federal funds expended to formulate and complete the ENERGY AGREEMENT AMONG THE STATE OF HAWAII, DIVISION OF CONSUMER ADVOCACY OF THE DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS, AND THE HAWAIIAN ELECTRIC COMPANIES (dated October, 2008).

6. All records of federal funds expended to implement the "Big Wind Projects" component of the ENERGY AGREEMENT AMONG THE STATE OF HAWAII, DIVISION OF CONSUMER ADVOCACY OF THE DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS, AND THE HAWAIIAN ELECTRIC COMPANIES (dated October, 2008).

7. All records of federal assistance provided to implement the "Big Wind Projects" component of the ENERGY AGREEMENT AMONG THE STATE OF HAWAII, DIVISION OF CONSUMER ADVOCACY OF THE DEPARTMENT OF COMMERCE AND CONSUMER AFFAIRS, AND THE HAWAIIAN ELECTRIC COMPANIES (dated October, 2008) including but not limited to: loan guarantees, tax credits, and tax deductions.

If it is your position that records exist that are responsive to this request, but that those records are exempt from disclosure pursuant to 10 C.F.R. § 1004.10, please identify the records that are being withheld and state the basis for denial for each record withheld. In addition, please provide the non-exempt portions of the records.

Request for Fee Waiver

NHLC hereby requests that all fees in connection with this FOIA request be waived in accordance with 10 C.F.R. § 1004.9(a)(8) which states, "the DOE will furnish documents without charge or at reduced charges if disclosure of the information is in the public interest because it is likely to contribute significantly to public understanding of the operations or activities of the government and disclosure is not primarily in the commercial interest of the requester." NHLC qualifies because the requested documents will significantly contribute to the public's understanding of the operations and activities of the DOE by illuminating the process and criteria used by DOE to formulate energy policy for Hawaii. The materials will not be used for NHLC's commercial use or gain.

NHLC is a non-profit organization that provides legal assistance to families and communities engaged in perpetuating the culture and traditions of Hawai'i's indigenous people.

NHLC asks for a waiver of all fees for locating and duplicating the requested records. If a waiver is not granted, please advise NHLC of the amount of any proposed search, review, and reproduction charges before those activities are carried out. NHLC expects a response within ten (10) working days as provided by 10 C.F.R. § 1004.5(d). If you have any questions, please contact Sharla Manley at (808) 521-2302.

Sincerely,

Sharla Manley
Staff Attorney

Peterson, Emily (CONTR)

From: Spaeth, Jim (GO)
Sent: Thursday, December 13, 2012 4:28 PM
To: Lindenberg, Steve; Parks, William
Subject: FW: LCA recommendations for HECO - are these correct? What else do we need to include?
Attachments: NREL Harmonization formulas.docx

Steve, Bill,
FYI, Asia Yeary is asking DOE to support an EPA recommendation that for the IRP process, HECO perform GHG emissions estimates for all of their scenarios. The details of the proposal are described below. The consensus from prior conversations with the group copied below was that a complete LCA for all of these scenarios is not a realistic ask given the resources and time it would require.

This approach seems reasonable to me. Any thoughts? We can discuss it tomorrow if you like.

Thanks,
Jim

From: Yeary.Asia@epamail.epa.gov [mailto:Yeary.Asia@epamail.epa.gov]
Sent: Tuesday, December 11, 2012 6:10 PM
To: Yeary.Asia@epamail.epa.gov
Cc: Machol.Ben@epamail.epa.gov; Gonzalez.Michael@epamail.epa.gov; Spaeth, Jim; Kelly, Kenneth; makenaka@hawaii.edu; Matthias Fripp; Richard Wallsgrove
Subject: LCA recommendations for HECO - are these correct? What else do we need to include?

What a great conversation! Thank you all! Thank you Garvin!

I want to make sure I understood our conclusion. Did we decide to suggest that HECO:

#1. Incorporate the information from these two key figures into the IRP Strategist model used to compare different energy scenarios.

http://www.nrel.gov/docs/fy13osti/57229.pdf Slide #13

ttp://www.nrel.gov/docs/fy13osti/55538.pdf Figure 1

#2. Use the IPCC published Harmonization formulas (attached) for developing first order estimates of life cycle GHG emissions from selected electricity generation technologies or project-specific adjustments to generic harmonization results and incorporate these results into the IRP Strategist model used to compare different energy scenarios.

Is this correct? At this time, we are not going to ask them to work on a Hawaii specific LCA study to compare LNG to Oil, etc. correct?

How much background information do we need to provide in to the IRP post? Can we keep it simple and provide the links for #1 & #2 and the harmonization formula attachment?

Thanks for all your help! I just want to make sure we are doing what's most helpful and effective.

Happy Friday!

Warm aloha,

Asia Yeary
U.S. EPA Region 9
Hawaii Sustainability Coordinator
Grants Project Officer
808-342-5675

Formulas for developing first order estimates of life cycle GHG emissions from selected electricity generation technologies or project-specific adjustments to generic harmonized results

Natural Gas

$$GHG_{pr} = FC * \frac{\eta_{h,t}}{\eta_{pr}} * \frac{HV_{h,t}}{HV_{pr}} * \left[GHG_{med,t} + ML_{adj}\right] + (1 - FC) * GHG_{med,t}$$

Where

GHG_{pr} = estimated life cycle GHG emissions for the analyzed project, pr (g CO_2-eq/kWh);

FC = fraction of life cycle GHG emissions modulated by natural gas fuel cycle (default = 99%);

$\eta_{h,t}$ = harmonized thermal efficiency estimate used in the present study by technology, t;

$\eta_{h,t}$ = thermal efficiency for the analyzed project;

$HV_{h,t}$ = harmonized natural gas heating value estimate used in the present study;

HV_{pr} = natural gas heating value for the analyzed project;

$GHG_{med,t}$ = median GHG emissions from table 2 for the proposed project technology, t, harmonized by all parameters (g CO_2-eq/kWh)

ML_{adj}: Optional methane leakage adjustment – can omit if unknown

$$ML_{adj} = GHG_{ml} * \left(ML_{pr} - ML_{h} - 1\right)$$

ML_{pr} = methane leakage estimate for proposed project (%);

ML_{h} = methane leakage for harmonized GHG emission estimates in table 2 (default = 1.2%);

GHG_{ml} = estimated non-combustion GHG emissions per percent methane leakage (default = 60 g CO_2-eq/kWh)

Crystalline Silicon PV

The harmonization methodology is described in the context of the equation needed to calculate the

GHG emissions for solar PV:

$$GHG = \frac{W}{I \times \eta \times PR \times LT \times A} \qquad (1)$$

where *GHG* is the mass emissions of GHGs weighted by their global warming potentials (GWP) per unit electricity generated (g CO_2e per kWh),

W is the GWP-weighted mass of GHGs emitted over the lifetime of the PV system (g CO_2e),

I is the irradiation (kWh/m^2/yr),

η is the lifetime average module efficiency (%),

PR is the performance ratio,

LT is the system lifetime (yr), and

A is the total module area (m^2).

This calculation, used in most PV LCA studies, encompasses two characteristics of the technology. The numerator sums all of the GHG emissions from all components and life cycle phases and weights each GHG by GWP, while the denominator calculates the power output over the lifetime of the PV system. In the harmonization process, several factors affecting the denominator are standardized, and *GHG* is recalculated based on these new factors, producing a "harmonized" result.

Wind

Life cycle GHG emission estimates for wind power systems are calculated as follows:

$$\frac{CO_2 + \left(CH_4 * 25\ \frac{g\ CO_2e}{g\ CH_4}\right) + \left(N_2O * 298\ \frac{g\ CO_2e}{g\ N_2O}\right)}{Capacity\ Factor * 8760\ \frac{hours}{year} * Lifetime * Nameplate\ Capacity}$$

This equation allows for clear identification of the potential magnitude for adjustment in the life cycle GHG emission estimates that each of the harmonization parameters has. The numerator represents the total emissions over the life cycle, while the denominator represents the lifetime power output of the system. The GWP harmonization step adjusts two of the values in the summation in the numerator, however, the CO_2 portion of the emission estimates remain unchanged. The capacity factor and system lifetime harmonization steps both scale the denominator in its entirety, and therefore have a larger potential to adjust the life cycle GHG emission estimates than GWP harmonization has. The system boundary harmonization step adds additional emissions onto the numerator to account for life cycle stages what were not included in the scope of the original analysis. Thus, this harmonization step has a potential for adjustment of the life cycle GHG emission estimates similar to that of the GWP harmonization step.

CSP

S1. Estimating LC GHG Emissions of CSP Plants with Varying Environmental and Performance Characteristics

Because the overall environmental performance of a CSP plant is influenced by several parameters, it is useful to understand how LC GHG emissions are affected by different values assigned to those parameters. The following sections outline a method that policy-makers and LCA practitioners can to use to estimate the LC GHG emissions of a CSP plant under a variety of conditions. By way of equations (1-6), this approach allows for the adjustment of our harmonized estimate of LC GHG emissions from trough and tower CSP plants for each harmonization parameter independently.

Again, the reader should keep in mind, the most accurate approximation of the LC GHG emissions associated with a specific CSP plant design will always be obtained by conducting a full LCA using site-specific data.

<heading level 2> Light Harmonization Parameter Values and Results

The harmonized value for each light harmonization parameter for trough and tower technologies are listed below.

- Direct Normal Irradiance (DNI): $DNI_{harm} = 2{,}400$ [kWh/m^2/yr]
- Lifetime: $LT_{harm} = 30$ [years]
- Solar-to-Electric Efficiency: $\eta_{harm}^{PT} = 0.15$ [unitless]
  $\eta_{harm}^{CR} = 0.20$ [unitless]
- Solar Fraction: $SF_{harm} = 1$ [unitless]

Refer to the variable definitions provided above for all equations shown in the following subsections.

Recall that auxiliary natural gas combustion and electricity consumption are removed from the published estimates during light harmonization. The GHG contributions from these activities can be estimated for addition to LC GHG emissions using the instructions provided in the following sections (entitled "Auxiliary Natural Gas Combustion" and "Electricity Consumption").

Note: The values of GWPs for GHGs cannot be varied using the simplified approach described here. As mentioned in the manuscript, harmonization by GWPs has a limited impact on the overall LC GHG emissions of a CSP plant.

The median values of LC GHG emissions obtained from light harmonization (as shown in Table 3 of the manuscript), for the trough and tower technologies, are listed below.

- Parabolic Trough (i.e. Trough): $GHG_{harm}^{PT} = 22$ [g CO_{2eq}/kWh]
- Central Receiver (i.e. Tower): $GHG_{harm}^{CR} = 23$ [g CO_{2eq}/kWh]

Use following equations and the values listed above to adjust the harmonized estimates of life cycle GHG emissions for trough and tower CSP based on user-defined harmonization values.

<heading level 3> Direct Normal Irradiance (DNI):

Parabolic Trough: $$GHG_{DNI}^{PT} = \frac{GHG_{harm}^{PT} DNI_{harm}}{DNI} \quad (1a)$$

Central Receiver: $$GHG_{DNI}^{CR} = \frac{GHG_{harm}^{CR} DNI_{harm}}{DNI} \quad (1b)$$

Note: DNI = desired value of direct normal irradiance

<heading level 3> Lifetime

Parabolic Trough: $$GHG_{LT}^{PT} = \frac{GHG_{harm}^{PT} LT_{harm}}{LT} \quad (2a)$$

Central Receiver: $$GHG_{LT}^{CR} = \frac{GHG_{harm}^{CR} LT_{harm}}{LT} \quad (2b)$$

Note: LT = desired value of plant lifetime

<heading level 3> Solar-to-Electric Efficiency

Parabolic Trough: $$GHG_{\eta}^{PT} = \frac{GHG_{harm}^{PT} \eta_{harm}^{PT}}{\eta} \quad (3a)$$

Central Receiver: $$GHG_{\eta}^{CR} = \frac{GHG_{harm}^{CR} \eta_{harm}^{CR}}{\eta} \quad (3b)$$

Note: η = desired value of solar-to-electric efficiency

<heading level 3> Solar Fraction

Note: This harmonization parameter requires the reader to select a hypothetical capacity and capacity factor of the plant under investigation.

Step 1: Identify the net capacity of the CSP plant under investigation.

Step 2: Identify the capacity factor, based on solar-only operation, of the CSP plant under investigation.

Step 3: Select the target capacity factor that is to be achieved by switching to hybrid operation.

Step 4: Identify the assumed boiler and power block efficiencies of the CSP plant under investigation.

Step 5: Determine the mass of GHGs emitted per MJ (i.e., the GWI) of natural gas combusted. As a reference, Table S8 provides the GWIs for four natural gas combustion options considered on a life cycle basis (i.e., including extraction, processing, transport and combustion of natural gas) (Swiss Center for Life Cycle Inventories, 2010):

a) >100 kW boiler duty with U.S. electricity grid used for upstream processes: 0.072 kg CO_{2eq}/MJ
b) <100 kW boiler duty with U.S. electricity grid used for upstream processes: 0.077 kg CO_{2eq}/MJ
c) >100 kW boiler duty with European average electricity grid used for upstream processes: 0.071 kg CO_{2eq}/MJ
d) <100 kW boiler duty with European average electricity grid used for upstream processes: 0.076 kg CO_{2eq}/MJ

Step 6: Using the selected values of the variables described in Steps 1–5, complete the following series of equations (4a through 4e or 4f) in succession.

$$E_{el-gas} = 8{,}760\left[\left(CF_{hyb} - CF_{sol}\right)(P)\right] * 1{,}000 \qquad (4a)$$

$$E_{th-gas} = \frac{3.6 * E_{el-gas}}{(\eta_b \eta_p)} \qquad (4b)$$

$$M_{gas} = E_{th-gas} \cdot GWI_{gas} \qquad (4c)$$

$$GHG_{gas}^{LC} = \frac{M_{gas}}{(P*CF_{hyb}*8760)} \quad (4d)$$

Parabolic Trough: $$GHG_{SF}^{PT} = GHG_{harm}^{PT}\frac{CF_{sol}}{CF_{hyb}} + GHG_{gas}^{LC} \quad (4e)$$

Central Receiver: $$GHG_{SF}^{CR} = GHG_{harm}^{CR}\frac{CF_{sol}}{CF_{hyb}} + GHG_{gas}^{LC} \quad (4f)$$

where

E_{el-gas} = the annual electrical energy that will be provided from natural gas combustion based on the selected capacity factor [kWh/yr] (the factor of 1000 converts MWh to kWh)

CF_{hyb} = the desired capacity factor to achieve from hybrid operation [unitless]

CF_{sol} = the capacity factor of the CSP plant under investigation (solar-only operation) [unitless]

P = the net capacity of the CSP plant under investigation [MW]

LT = the assumed lifetime of the CSP plant under investigation [yr]

E_{th-gas} = the annual amount of thermal energy that must be provided by natural gas combustion to produce the required amount of electricity calculated in equation (4a) [MJ/yr]

η_b = the efficiency of the boiler used in the CSP plant under investigation [unitless]

η_p = the efficiency of the power block used in the CSP plant under investigation [unitless]

M_{gas} = the annual mass of GHGs released during natural gas combustion [kg CO_{2eq}/yr]

GHG_{gas}^{LC} = the LC GHG emissions, normalized by lifetime electricity production (based on CF_{hyb}) resulting from t years of natural gas combustion during hybrid operation [g CO_{2eq}/kWh]

GHG_{SF}^{PT} = the adjusted LC GHG emissions of the specified trough CSP plant, harmonized by solar fraction [g CO_{2eq}/kWh]

GHG_{SF}^{CR} = the adjusted LC GHG emissions of the specified trough CSP plant, harmonized by solar fraction [g CO_{2eq}/kWh]

Note: 8,760 refers to the number of hours in a year and 3.6 refers to the number of MJ in a kWh.

<heading level 3> Auxiliary Natural Gas Combustion

Note: This harmonization parameter requires the reader to select a hypothetical capacity, capacity factor, and lifetime of the plant under investigation.

Step 1: Identify the net capacity of the CSP plant under investigation.

Step 2: Identify the capacity factor, based on solar-only operation, of the CSP plant under investigation.

Step 3: Identify the lifetime of the CSP plant under investigation.

Step 4: Determine how much auxiliary natural gas must be combusted be year (as a reference, Burkhardt et al. (2011) assumes 91,000 MJ/MW/yr).

Step 5: Identify the assumed boiler CSP plant under investigation.

Step 6: Determine the mass of GHGs emitted per MJ (i.e. the GWI) of natural gas combusted. As a reference, Table S8 provides the GWIs for four natural gas combustion options considered on a life cycle basis (i.e., including extraction, processing, transport and combustion of natural gas) (Swiss Center for Life Cycle Inventories, 2010):

a) >100 kW boiler duty with U.S. electricity grid used for upstream processes: 0.072 kg CO_{2eq}/MJ
b) <100 kW boiler duty with U.S. electricity grid used for upstream processes: 0.077 kg CO_{2eq}/MJ
c) >100 kW boiler duty with European average electricity grid used for upstream processes: 0.071 kg CO_{2eq}/MJ
d) <100 kW boiler duty with European average electricity grid used for upstream processes: 0.076 kg CO_{2eq}/MJ

Step 7: Using the selected values of the variables described in Steps 1–6, complete the following series of equations (5a through 5d or 5e) in succession.

$$E_{th-gas} = NG \cdot P \cdot LT \quad (5a)$$

$$M_{gas} = E_{th-gas} \cdot GWI_{gas} \quad (5b)$$

$$GHG_{gas}^{LC} = \frac{M_{gas}}{(P*CF*LT*8760)} \quad (5c)$$

Parabolic Trough: $GHG_{NG}^{PT} = GHG_{harm}^{PT} + GHG_{gas}^{LC}$ (5d)

Central Receiver: $GHG_{NG}^{CR} = GHG_{harm}^{CR} + GHG_{gas}^{LC}$ (5e)

where,

NG = the annual amount of thermal energy that must be provided by auxiliary natural gas combustion per MW of capacity and per year, as identified in step 4 [MJ/MW/yr]

E_{th-gas} = the amount of thermal energy that must be provided by auxiliary natural gas combustion during the plant lifetime [MJ]

P = the net capacity of the CSP plant under investigation, as identified in step 1 [MW]

CF = the capacity factor of the CSP plant under investigation (solar-only operation), as identified in step 2 [unitless]

LT = the assumed lifetime of the CSP plant under investigation, as identified in step 3 [yr]

M_{gas} = the mass of GHGs released during natural gas combustion over the plant's lifetime [kg CO_{2eq}]

GWI_{gas} = the life cycle GHG emissions associated with the consumption of 1 MJ of natural gas [kg CO_{2eq}/MJ]

GHG_{gas}^{LC} = the LC GHG emissions, normalized by lifetime electricity production (based on CF) resulting from LT years of natural gas combustion during hybrid operation [g CO_{2eq}/kWh]

GHG_{NG}^{PT} = the new LC GHG emissions of the specified trough CSP plant, harmonized by auxiliary natural gas combustion [g CO_{2eq}/kWh]

GHG_{NG}^{CR} = the new LC GHG emissions of the specified tower CSP plant, harmonized by auxiliary natural gas combustion [g CO_{2eq}/kWh]

<heading level 3> Auxiliary Electricity Consumption

Note: This harmonization parameter requires the reader to select a hypothetical capacity, capacity factor, and lifetime of the plant under investigation.

Step 1: Identify the net capacity of the CSP plant under investigation.

Step 2: Identify the capacity factor, based on solar-only operation, of the CSP plant under investigation.

Step 3: Identify the lifetime of the CSP plant under investigation.

Step 4: Determine how much auxiliary electricity must be consumed per year (as a reference, Burkhardt et al. (2011) assumes 36 MWh/MW/yr).

Step 5: Determine the amount of GHGs emitted per kWh (i.e., the GWI) of electricity produced by the desired regional electrical grid. As a reference, Table S8 provides the GWIs for two regional grids (US = 0.77 kg CO_{2eq}/kWh; Germany = 0.66 kg CO_{2eq}/kWh).

Step 6: Using the selected values of the variables described in Steps 1–5, complete the following series of equations (6a–6d) in succession.

$$M_{elec} = (EC \cdot P \cdot LT \cdot GWI_{elec}) \cdot 1{,}000 \quad (6a)$$

$$GHG_{elec}^{LC} = \frac{M_{elec}}{(P * CF * LT * 8760)} \quad (6b)$$

Parabolic Trough: $GHG_{elec}^{PT} = GHG_{harm}^{PT} + GHG_{elec}^{LC}$ (6c)

Central Receiver: $GHG_{elec}^{CR} = GHG_{harm}^{CR} + GHG_{elec}^{LC}$ (6d)

where,

EC = the annual amount of electricity that is consumed per MW of capacity, as identified in step 4 [MWh/MW/yr]

P = the net capacity of the CSP plant under investigation, as identified in step 1 [MW]

CF = the capacity factor of the CSP plant under investigation (solar-only operation), as identified in step 2 [unitless]

LT = the assumed lifetime of the CSP plant under investigation, as identified in step 3 [yr]

GWI_{elec} = the life cycle GHG emissions associated with the production of 1 kWh of electricity [kg CO_{2eq}/kWh]

M_{elec} = the mass of GHGs associated with electricity consumption over the plant's lifetime [g CO_{2eq}]

GHG_{elec}^{LC} = the LC GHG emissions, normalized by lifetime electricity production (based on CF) resulting from LT years of electricity consumption [g CO_{2eq}/kWh]

GHG_{elec}^{PT} = the new LC GHG emissions of the specified trough CSP plant, harmonized by auxiliary electricity consumption [g CO_{2eq}/kWh]

GHG_{elec}^{CR} = the new LC GHG emissions of the specified tower CSP plant, harmonized by auxiliary electricity comnsumption [g CO_{2eq}/kWh]

Note: The conversion factor of 1,000, seen in equation (6a), converts MWh to kWh.

Coal

Equation 3 uses the principles of CEF harmonization to adjust the median harmonized estimate to project-specific conditions by harmonizing project GHG emissions that depend directly on the amount of coal burned including coal mine, preparation, transport, and combustion. The fraction of life cycle GHG emissions modulated by the coal fuel cycle (including combustion) is assumed to be 99% for all technologies. IQR values can be adjusted similarly to provide a first-order estimate of a reasonable range of life cycle GHG emissions for project-specific conditions with further customization possible if factors such as likely coal mine methane emissions are known.

$$GHG_{pr} = FC * \frac{CEF_{h,t}}{CEF_{pr}} * GHG_{med,t} + (1 - FC) * GHG_{med,t} \quad (3)$$

Where:

– GHG_{pr} = The estimated life cycle GHG emissions for the analyzed project, *pr* (g CO_2e/kWh);

– FC = Assumed fraction of life cycle GHG emissions modulated by the coal fuel cycle;

(default = 99%);

– $CEF_{h,t}$ = The harmonized CEF estimate used in the present study by technology, *t* (g CO_2/kWh);

– CEF_{pr} = The CEF calculated for the analyzed power plant project, *pr* (g CO_2/kWh); and

– $GHG_{med,t}$ = The median GHG emissions from Table 2 for the proposed project technology, *t*, harmonized by all parameters (g CO_2e/kWh).